(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : 0 452 126 A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number : 91303209.0

(22) Date of filing : 11.04.91

(51) Int. Cl.^{5} : E21B 23/00, E21B 43/116, E21B 43/119, E21B 17/10, E21B 47/024

(30) Priority : 12.04.90 US 508749

(43) Date of publication of application : 16.10.91 Bulletin 91/42

(84) Designated Contracting States : DE FR GB NL

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(54) Apparatus for orienting perforating gun.

(57) A downhole perforating tool (20) includes a perforating gun container (47) and at least one eccentrically mounted rotatable weight member (36,56). The weight members and the gun can be releasably coupled at any desired angular orientation by releasable coupling means (40,55). The tool further includes at least two spaced circumferential sleeves (30,60) to contact the borehole wall. Upon lowering the tool into a deviated well with the gun and weight member coupled at a predetermined angle, the weight member turns under the influence of gravity to adopt a lowermost position, so also rotating the perforating gun. The gun is thus positioned at the desired angle in the well borehole.

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This invention relates to well perforating and in particular to the orientation of a perforating gun in a deviated well to line up with the formation to be perforated.

It is not uncommon nowadays to drill deviated or slant wells, especially from offshore platforms and the like. For instance, once a producing field has been discovered, one of the next steps is to install a platform at a proper location in the field. The platform may support the well head equipment for numerous wells, perhaps as many as sixty-four. Needless to say, while all sixty-four wells may come together at the platform, they terminate at multiple locations across the formation of interest. This involves the drilling of deviated wells from the platform. Several such wells are drilled in which a substantial portion of each well is inclined from the vertical. It is not uncommon to have an inclination of as much as fifty, and even up to about seventy degrees deviation from the vertical.

The positioning of tools such as perforating guns in deviated wells presents a number of problems. Not only does the well deviation itself give rise to certain difficulties, but in addition the formation to be perforated may well not itself be truly horizontal. In particular, the formations can slope upwardly or downwardly with respect to a horizontal reference plane. They might be as much as forty, fifty or even sixty degrees inclined from the horizontal reference. Moreover, formations have a type of grain which extends through them. This is sometimes known as the formation bedding plane or the fracture plane. These are planes which are found within the formation and which define a preference (which may very strong) for production fluid flow.

Heretofore, it has been impossible to lower a perforating gun on a wireline to a particular formation and operate that perforating gun so that perforations are accurately positioned at an angle where the perforations are parallel to the bedding plane of the formation. In other words, there has been no known approach for positioning the perforations so that they extend along the grain of the formation with surface, real time verification of position. We have now devised a method and apparatus for accomplishing this.

According to the present invention, there is provided an apparatus for orienting a perforating gun in a deviated well borehole, which apparatus comprises an elongate tool body having upper and lower ends and defining an axis of rotation; at least two spaced apart, circumferential cylindrical sleeves encircling said tool body and having bearing means to enable said tool body to rotate internally relative to said sleeves; weight means positioned between said sleeves and located eccentrically relative to the axis of rotation; an elongated perforating gun carrier sleeve for supporting a plurality of shaped charges, said carrier sleeve being positioned between said circumferential cylindrical sleeves and releasably connected to said weight means for rotational movement therewith; and means for releasably locking said elongated perforating gun carrier sleeve to said weight means such that shaped charges supported by said perforating gun carrier sleeve can be locked at a predetermined angular position relative to the eccentrically located weight of the weight means.

The invention also includes a method of positioning a perforating gun in a deviated well borehole oriented adjacent a formation of interest wherein, in an apparatus of the invention, the gun carrier sleeve is locked at a predetermined angular position relative to the weight means, and the apparatus is then lowered on a wireline into the wellbore to a depth at which the gun sleeve is adjacent the formation of interest.

In order that the invention may be more fully understood, embodiments thereof will not be described by way of illustration only, with reference to the accompanying drawings, wherein:

Fig. 1 is a schematic vertical section of a deviated well of the sort in which the apparatus of the present invention can be used;

Fig. 2 is a cross-sectional view through the deviated well of Fig. 1 taken along the line 2-2 of Fig. 1 (but on a larger scale) ; and

Fig. 3 is a vertical section of one embodiment of perforating gun assembly tool of the present invention.

Referring to Fig. 1 of the drawings, a deviated well 10 extends from a drilling rig 11 which is at the surface, either on land or at sea. The deviated well 10 extends at some angle, i.e. it deviates from the vertical. A vertical reference direction is indicated by the arrow 12. The direction of the well in that region is indicated by the arrow 13. The angle between the lines 12 and 13 is the angle of deviation. It can be as much as seventy degrees or so. Typically, the well is cased and the casing is cemented in place. Locations along the cased well can be determined by utilizing a casing collar locator (CCL) so that a formation of interest can be located. The formation of interest is indicated generally by the numeral 14 in Fig. 2 of the drawings.

The formation 14 extends at an angle 15 with respect to the horizontal reference line shown in Fig. 2 of the drawings. The vertical reference 12 again is reproduced in Fig. 2. Thus, the vertical reference 12 defines the horizon which serves as a reference. It is important to note that the formation 14 includes formation bedding planes 16 which extend with the formation. These define what is, loosely speaking, formation grain. The formation grain makes it highly desirable that perforations are formed parallel to the bedding plane 16. It is generally desirable that the perforations formed be precisely parallel. Obviously, this type of precision is not essential but it is highly desirable that the perforations extend approximately or close to the bedding plane angle. The perforations 17 shown in Fig. 2 are almost parallel to the formation bedding

plane. This enables the perforations to take advantage of the natural flow channels found in the formation so that production is enhanced. As will be further understood, Fig. 2 is taken through the formation and only two perforations are shown, one extending up in the formation and the other extending downwardly in the formation. It is desirable that multiple formations be formed parallel to the perforations 17 shown in Fig. 2. They will all collectively be parallel to each other and hence or ideally parallel to the bedding plane 16 of the formation 14.

The circumstances in which the present procedure is usually carried out should be noted. The present procedure is normally a completion procedure. That is, the well has been drilled and it has been determined that there is sufficient interest in production that the well should be csed and the casing cemented in place. Moreover, it is normally known in advance what particular formation is the production zone, and information about that zone is obtained. This information includes the angle 15 which describes the angle of the formation bedding plane with respect to the horizontal reference, see Fig. 2. In other words, the angle 15 is known at this juncture. Typically, a survey of the well 10 is also run and this provides a map or chart of the path of the well. Thus, the slant or deviation angle of the well is also known in advance. It is generally known that the zone has a specified thickness also. With this information, a tool of the present invention is then used to form the perforations which will be described. Going now to Fig. 3 of the drawings, one embodiment of tool of the present invention is shown in a cased well. The description will proceed from top to bottom. Fig. 3 is formed of several sequential sections which are illustrated in sequence to provide a full description of the apparatus.

The tool is indicated generally by the numeral 20. It incorporates a cable head assembly for attachment to the wireline at 21. It is typically run in the well by connection with a wireline which connects at the cable head and suitable electrical connections are also included. These communicate through the wireline and connect to various components of the tool as will be described. The top end of the tool incorporates a swivel 22, typically a purchased item, which in the preferred embodiment is a pressure balanced wireline swivel which cancels torque from the wireline as it is reeled from the storage drum and extended in the well 10. In addition, the tool supports a navigation package 23 preferably containing a gravity operated pendulum connecting with a potentiometer which provides a signal for the surface. The signal indicates the angle of perforating shot plane of the tool with respect to the vertical. The tool also includes a casing collar locator (CCL) 24. The CCL detects the location of the casing collars to enable the perforating gun assembly 20 to be located at the correct depth in the well.

An axial passage 25 provides an electrical pathway for conductors which extend through the tool from the very top to the bottom. One conductor extends to the bottom of the perforating assembly 20 to operate a detonator mechanism. Passage 25 extends through a sub 26, and the sub has an axial bore therethrough as mentioned which is countersunk to receive a mandrel 27. The mandrel 27 continues therebelow. The mandrel 27 is surrounded by a skirt 28 at the upper end, the skirt being appended to the sub 26 and formed integrally therewith. These two members are preferably threaded together and are joined when the tool is assembled. The skirt 28, however, terminates at the lower end and supports an abutting bearing assembly 29. The bearing assembly in turn supports a spaced sleeve 30. The sleeve 30 is supported by a similar bearing assembly 31 at its lower end. Both bearing assemblies are locked in place. They permit the sleeve 30 to rotate freely. The sleeve supports one or more rollers 32 for freewheeling motion on an axle 33. There is a window cut in the sleeve to enable the roller to extend outwardly. In the preferred embodiment, there are two sets of rollers supported by the sleeve at different elevations, and hence, they are shown offset along the length of the tool. Moreover, the rollers are duplicated. For instance, two sets of three or four rollers typically will suffice. The sleeve is able to rotate in either direction and thereby functions as a type of cradle assembly for the tool. The rollers contact the surrounding casing that makes up the well borehole. It is not essential that the rollers contact at all points around the circle which confines the tool within the casing. Rather, the maximum diameter of the tool measured at the rollers is something less so that the tool is able to traverse locations where the casing is not perfectly circular. Moreover, the rollers 32 are sized so that they contact on what might be termed the bottom side of the tool. Fig. 3 shows the tool in a vertical position as when it is first placed in the well. When the tool reaches a deviated part of the well, however, one roller (eg. that on the left) will be on the low side of the tool and tend to support the weight of the tool while the roller on the other side will be on the high side and typically will not contact the surrounding casing. This clearance enables the sleeve 30 to rotate left or right. It also enables the tool to slide down the cased well 10 supported on the wireline until it reaches the depth of the formation shown in Fig. 2.

The mandrel 27 threads into an eccentric sub 35. This has an offset enlargement 36 which is eccentrically mounted. The eccentric weight 36 extends along the length of the sub. It hangs to the low side when permitted to rotate. The sub 35 rotates with the mandrel 27. The mass of the eccentric 36 is sufficient to cause rotation. When rotation of the mandrel 27 occurs, it rotates within the sleeve 30 which is connected to it by the upper and lower bearing assemblies previously described. The eccentric 36 thus hangs to the lower side. Thus, as viewed in Fig. 3, the left side

of Fig. 3 will be the bottom side. The eccentric 36 is axially drilled with the passage 37 which terminates at a larger chamber 38 to enable wiring communication through the tool. The eccentric is a portion of the sub 35 and it is shaped with a circular external surface. A shoulder 39 limits upward movement of a hollow lock nut 40. The lock nut 40 is threaded for locking purposes. This is described below.

The lock nut 40 has a lower peripheral edge 41 which abuts a lock ring 42. The ring 42 is received in an encircling groove 43 around the sub 35. Moreover, the sub 35 also abuts a shoulder 44 which is formed in an adjacent sub 45. The sub 45 has an upstanding internally threaded skirt 46. The lock nut 40 threads to the sub 45 at the threads on the skirt 46. Moreover, when the lock nut 40 is threaded to move upwardly, it disengages the lock ring 42. When the nut 40 is rotated in the opposite direction and is forced downwardly, it jams the lock ring 42 and forces the ring against the eccentric sub 35 so that the eccentric sub 35 is jammed against the sub 45 and held in fixed relationship on the shoulder 44. The subs 35 and 45 are thus locked together by the nut 40 when it is rotated to the down or locked position and they are free to relatively rotate when the lock nut 40 is in the up position.

The lock nut 40 is controllably installed to selectively fasten the subs 35 and 45 together so that they are prevented from relative rotation. Rotation is desirable so that the sub 45 can be rotated to a particular angle with respect to the eccentric 36. The purpose of this will be more apparent on description of the tool at the time of installing the shaped charges.

The sub 45 is threaded to an elongate perforating gun assembly 47. The gun 47 has an enclosure formed of an elongate sleeve which is an axially hollow sleeve which encloses one or more shaped charges pointing radially outwardly. The sleeve is provided with thin wall scallops 48 aligned with the shaped charges forming perforations at the circular scallops. The several shaped charges are supported by a common assembly aligned in the sleeve enclosure 47. This keeps all the debris after firing collected in the enclosing hollow sleeve 47. Preferably, rows of shaped charges are installed and they are aligned to fire in the same radial direction. There are rows of charges, one which can be seen in Fig. 3 and a duplicate or similar opposing set which form perforations 180° out of phase. In other words, perforations are made by the rows of shaped charges pointed in opposite directions. The sleeve has interior space to support the multiple shaped charges. As mentioned before, the passage 37 extends the connection pathway through the tool. The shaped charges are connected with a detonator mechanism located at the bottom of the perforating gun tool. The external sleeve, being axially hollow, is able to receive and support the necessary connections for rows of shaped charges. The preferred embodiment preferably includes two sets of shaped charges, the sets being positioned to form two opposing sets of perforations.

The housing connects with another sub 50 and is threaded to it in the same fashion as the sub 45 thereabove. The lock nut 40 is duplicated by the lock nut 55. This engages a similar ring 51 which causes the sub 50 to thread to and lock with a second eccentric sub 56. The passage 37 in the upper portion of the drawing is also extended at 52 through the sub 50 and again is extended at 53 through the eccentric sub 56. Since the lock nut 55 operates in the same fashion as the lock nut 40, it is believed that the foregoing description can likewise be applied to this lock nut so that it will be understood how the eccentric sub 56 is controllably locked to the elongate sleeve supporting the several shaped charges.

The eccentric sub 56 is drilled with an offset passage and supports a mandrel 58 which is similar in construction and purpose to the mandrel 27 previously mentioned. The mandrel 58 is threaded to the sub 56 thereabove. Thus, these two components move together as a unit. A bearing assembly 59 is shown therebelow and supports a surrounding sleeve 60 which is identical to the sleeve 30. It extends downwardly to another bearing assembly 61. In turn, this supports plural rollers 62 which are mounted on the appropriate axes 63. This enables a duplicate set of rollers to that shown at the top end of the tool to be positioned by the sleeve 60 for rotation. Moreover, the sleeve is able to rotate, thereby providing a mechanism whereby the sleeve operates as a cradle which permits the equipment passing through the center thereof to rotate. The upper sleeve 30 and the lower sleeve 60 are similar in construction and operation. The lower end of the mandrel 58 is threaded to an enclosed sub 65 having a chamber 66 for enclosing the detonation equipment. The mandrel 58 thereabove is provided with the axial passage 64 which extends through it and connects with the chamber 66. A conductor for firing is extended along the several passages shown in Fig. 3 and is received in the chamber 66 where it connects with the detonation equipment. In turn, the passage also received the conductors extending from the detonator back to the charges for operation of the charges.

Various and sundry seals are included to prevent leakage of any fluid in the well into the tool. Thus, the axial passage along the tool is sealed so that the firing equipment is not subjected to the intrusion of well fluid or elevated pressures.

The foregoing describes the structure of the apparatus. Its operation can be described by an example. For this purpose, assume that the well 10 has a region which is a slant well which is inclined at a 45° angle with respect to the vertical. Assume further, that the fracture bedding plane shown in Fig. 2 of the drawings is at an angle of 30° with respect to

the horizon. This means that the perforations on one side of the perforating gun assembly should be directed at an angle of 60° with respect to the vertical and the opposite set of perforations should be 180° out of phase because they are located on the opposite side of the perforating gun assembly. This is an angle of 30° which is implemented at the surface. It is implemented by first installing the sub 45 onto the sleeve 47 which houses the shaped charges within the sleeve behind the scallops 48. After installation, and with the lock nut 40 loose, the eccentric 36 is moved relative to the axis of the sleeve housing the shaped charges. As shown in Fig. 3, the perforating gun will form perforations which are perpendicular to the plane of the paper. The lock nut 40 is loosened, the threaded skirt 46 is rotated so that all the perforating guns supported by the tool are aligned in the new position relative to the eccentric 36. After that alignment has been accomplished, the lock nut 40 is then tightened by threaded engagement. This acts against the ring 42 and accomplishes tightening. The same activity is repeated at the lower end of the tool so the lock nut 55 is likewise fastened. When the two lock nuts are threaded up tight, the eccentric weights 36 and 56 hang to the side at a common azimuth with respect to the shaped charges supported by the sleeve 47. Between the two eccentric subs, the sleeve 47 and enclosed shaped charges are mounted eccentrically. The sleeve can be as short or long as needed; it is not uncommon for the sleeve to be twenty feet (6.1 m) long. In a longer length, the greater portion of tool weight is eccentered. For instance, in a 500 pound (227 kg) tool (with guns), as much as seventy-five or eighty percent of the weight is eccentric. The navigation package is turned on and its relative position to the eccentric weight is recorded.

The tool is then lowered into the well borehole. The CCL counts the casing collars as the tool travels downwardly. The tool travels rather smoothly because it is equipped with rollers, upper and lower rollers in particular, which enable it to travel smoothly. As it passes through the various casing collars, the depth of the tool in the well is determined. When it reaches the requisite depth based on casing collar count in conjunction with the schedule of pipe lengths involved in the casing string, the cable is held so that the tool can no longer travel. At this juncture, the navigation equipment forms an output signal which is indicative of the shaped charges phase orientation with respect to the vertical. Referring to Fig. 2, this equipment measures the angle of the perforating gun assembly with respect to the vertical reference 12. If this angle coincides with the angle which was thought to be correct, then the equipment has been determined to be at the right depth in the well and at the right angle of phase orientation. Time is permitted to pass so that the tool can rotate. Tool rotation involves the rotor carriages at the upper and lower ends of the tool. The rollers on the two sleeves contact the casing which defines the well borehole, and permit the tool to rotate along its lengthwise axis. This rotation is driven by the eccentrics which extend to a common azimuth. Here, it must be noted that the eccentrics are pointed in a particular direction when the tool is first placed in the well borehole. At the surface, however, the tool is vertical and the eccentrics are not free to fall to the gravity side or down side. As the well deviates from the vertical, and especially when it reaches a deviation of forty, fifty or even seventy degrees, the eccentrics fall to the low side of the well. This causes rotation of the entire tool. Rotation is not resisted by the cable which is connected to the tool because the tool includes the swivel mechanism 22 at the upper end and that permits the tool to rotate in either direction without bias and further permits it to rotate sufficiently that the eccentrics fall to the down or bottom side. The two eccentrics and perforating gun 47 thus move to the down side and define the vertical line 12 shown in Fig. 2. When that occurs, the shaped charges within the sleeve are then correctly positioned.

Because at surface assembly, the sleeve was rotated with respect to the eccentrics, it is thus now positioned so that the perforations 17 shown in Fig. 2 are formed as close as possible parallel to the formation bedding plane. This enables the perforations to have greater length and to extend deeper into the formation of interest, and to provide the resultant production. At this juncture, the tool can then be fired. The sequence therefore has the first step of determining that the tool is at the right well depth, then measuring the angle of orientation of the tool which measurement is compared by means of the navigation package with the anticipated orientation. If a match is obtained, this indicates the tool is at the right well depth and orientation with respect to the vertical reference. Time is permitted for the tool to rotate inside the roller mounted cradles at the upper and lower ends of the tool. If desired, while monitoring the navigation package data and recording at the surface the tool can be raised and lowered gently a few times, moving only a few feet on each stroke, all for the purpose of permitting rotation. Rotation is accomplished so that the perforating guns are then correctly referenced to the vertical lines in Figs. 1 and 2. This then positions the perforating guns for operation. A signal from the surface is transmitted down the wireline. It travels through conductors in the several passages through the tool to the chamber 66 at the lower end. The detonation equipment is located in that chamber, and in turn, that forms a signal producing detonation. That signal is conveyed to the various perforating charges and they are fired by that signal. After firing, the tool is retrieved on the wireline. It travels easily out of the well borehole because it is travelling in the slant well supported on rollers. When it is in the vertical part

of the well, contact with the casing is somewhat incidental. It can be retrieved quickly and at the surface, the sleeve and spent shaped charges in the sleeve is discarded and a gun assembly 47 is installed. If needed, the relative angle of the shaped charge (when fired) is adjusted by adjustment of the angular position of the threaded skirt 46 with respect to the eccentrics. In summary, the device can be readjusted so that each use of the device can move to a different angular direction.

Claims

1. An apparatus (20) for orienting a perforating gun in a deviated well borehole (10), which apparatus comprises an elongate tool body having upper and lower ends and defining an axis of rotation; at least two spaced apart, circumferential cylindrical sleeves (30,60) encircling said tool body and having bearing means (29,31;59,61) to enable said tool body to rotate internally relative to said sleeves; weight means (36,56) positioned between said sleeves and located eccentrically relative to the axis of rotation; an elongated perforating gun carrier sleeve (47) for supporting a plurality of shaped charges, said carrier sleeve being positioned between said circumferential cylindrical sleeves and releasably connected to said weight means for rotational movement therewith; and means (40,55) for releasably locking said elongated perforating gun carrier sleeve to said weight means such that shaped charges supported by said perforating gun carrier sleeve can be locked at a predetermined angular position relative to the eccentrically located weight of the weight means.

2. Apparatus according to claim 1, wherein said circumferential cylindrical sleeves (30,60) include roller means (32;62) having axes of rotation at right angles to said tool body axis of rotation mounted thereon for rolling contact with the well borehole wall.

3. Apparatus according to claim 2, wherein said roller means (32;62) include free wheeling rollers distributed circumferentially around said tool body.

4. Apparatus according to claim 1,2 or 3, wherein a plurality of said circumferential cylindrical sleeves (30;60) are located spaced along said tool body to support said tool body in a deviated well borehole.

5. Apparatus according to claim 1,2,3 or 4,wherein said releasable locking means (40,55) comprise a threadable lock nut advancable against a lock ring (42,51) to lock said elongated perforation gun carrier sleeve relative to said tool body.

6. Apparatus according to claim 5, wherein, from the locked position, said threadable lock nut is movable to a release position allowing relative rotational movement between said perforating gun carrier sleeve and tool body.

7. Apparatus according to any of claims 1 to 6, which also includes shaped charges in the gun carrier, and detonator means therefor.

8. A method of positioning a perforating gun in a deviated well borehole oriented adjacent a formation of interest wherein, in an apparatus as claimed in claim 7, the gun carrier sleeve is locked at a predetermined angular position relative to the weight means, and the apparatus is then lowered on a wireline into the wellbore to a depth at which the gun sleeve is adjacent the formation of interest.

9. A method of perforating a deviated well wherein a perforating gun is positioned in the well by the method of claim 8, and the gun is then detonated.

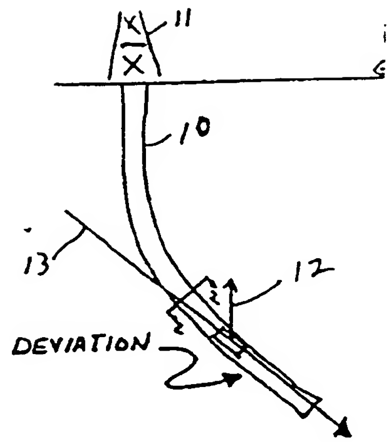

11
10
13
12
DEVIATION

Fig 1

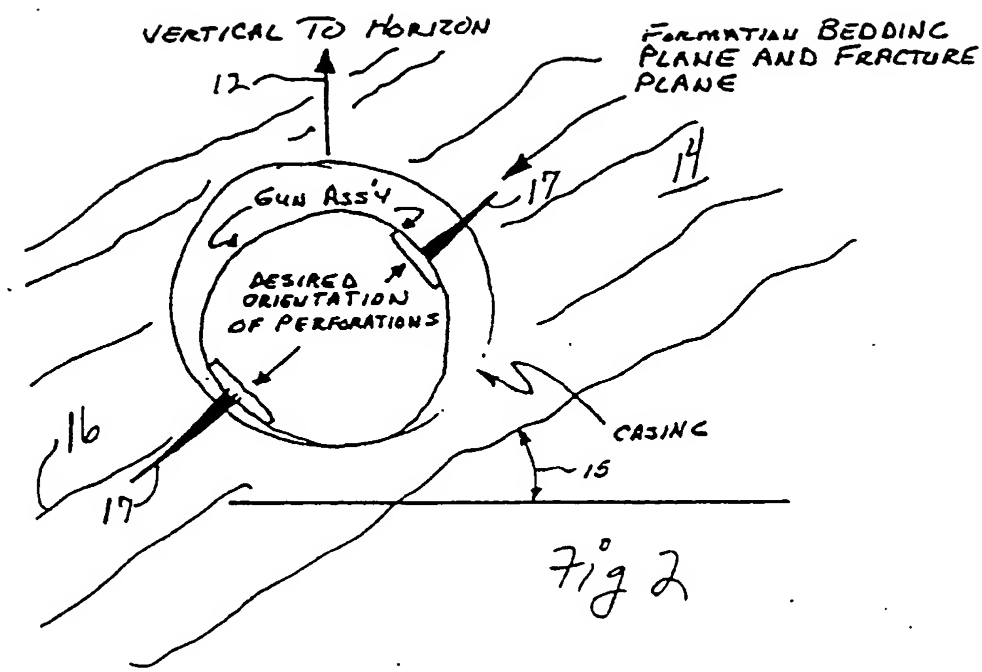

VERTICAL TO HORIZON
12
FORMATION BEDDING PLANE AND FRACTURE PLANE
14
17
GUN ASS'Y
DESIRED ORIENTATION OF PERFORATIONS
CASING
16
17
15

Fig 2

Fig 3

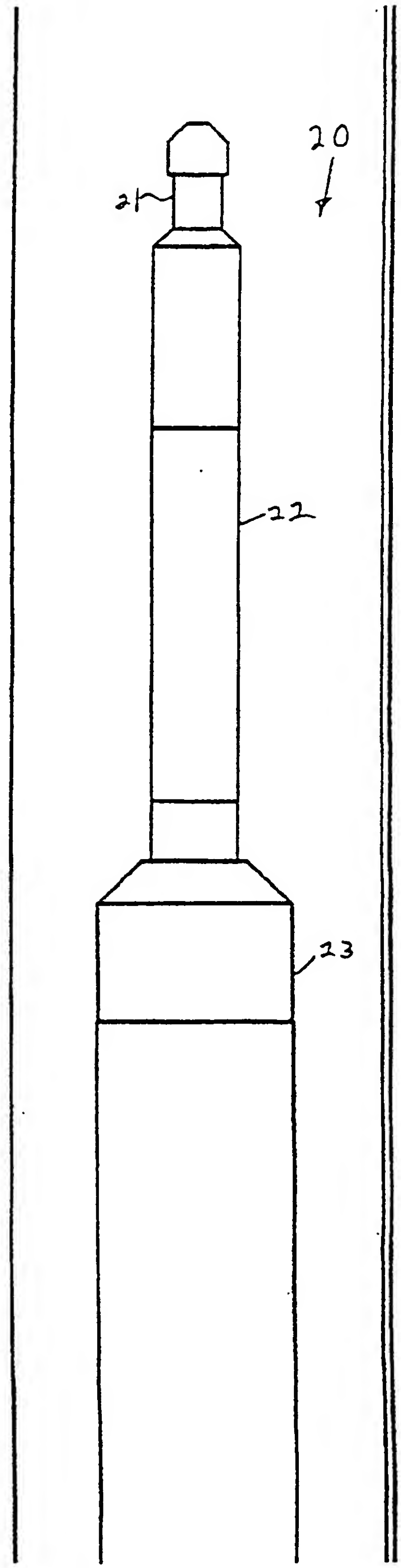


Fig 3A

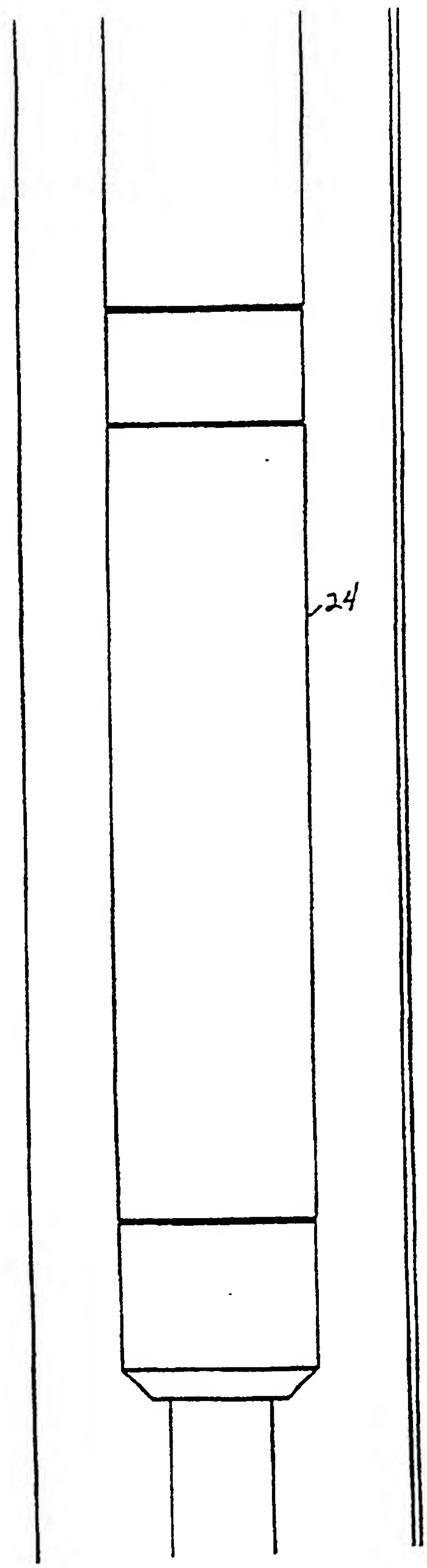


Fig 3B

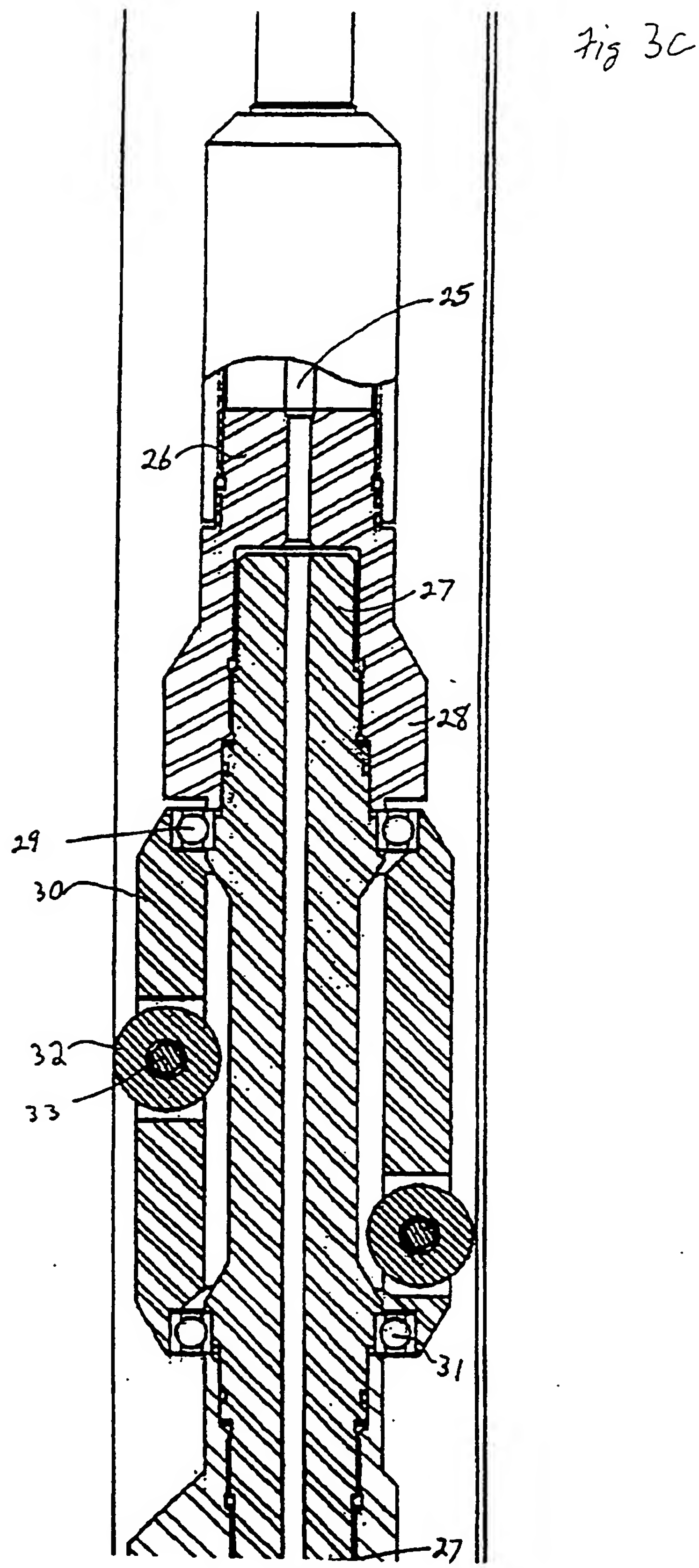


Fig 3c
25
26
27
28
29
30
32
33
31
27

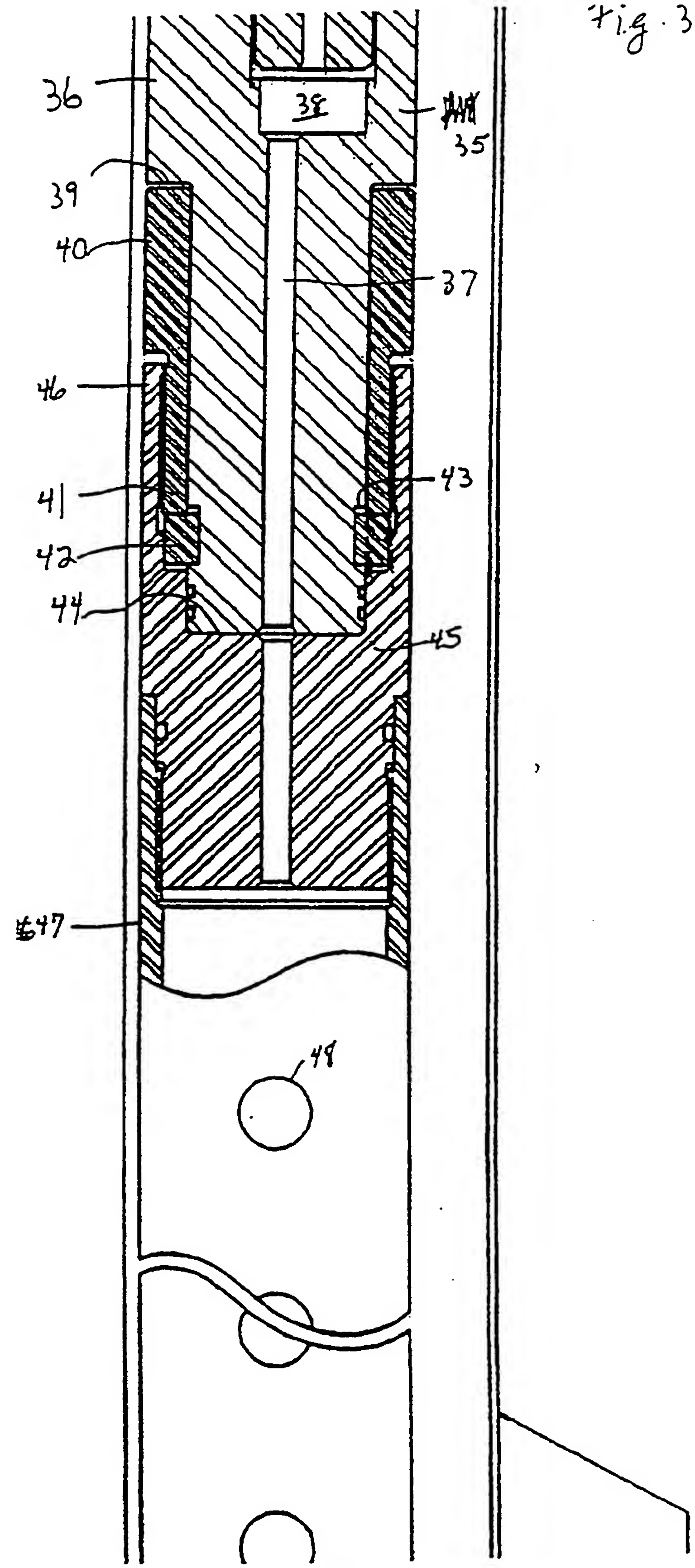


Fig. 3D

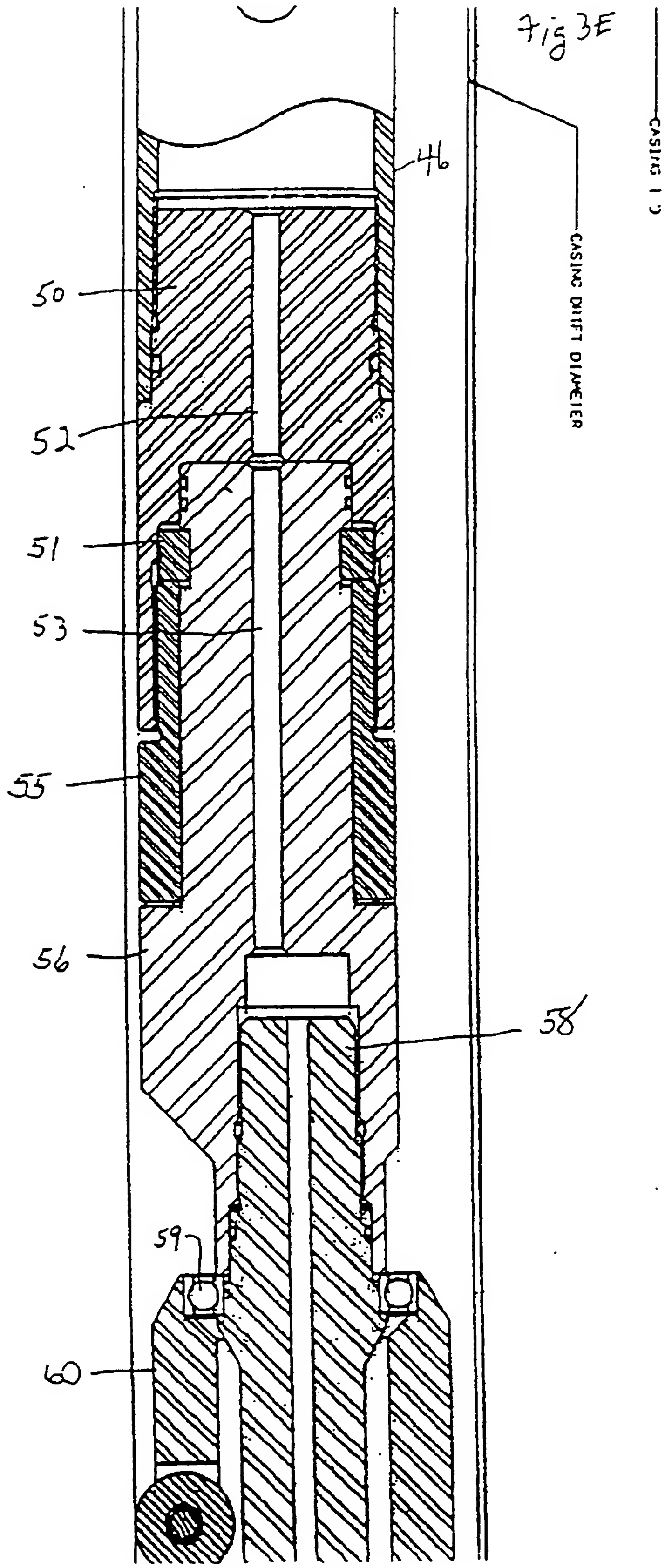
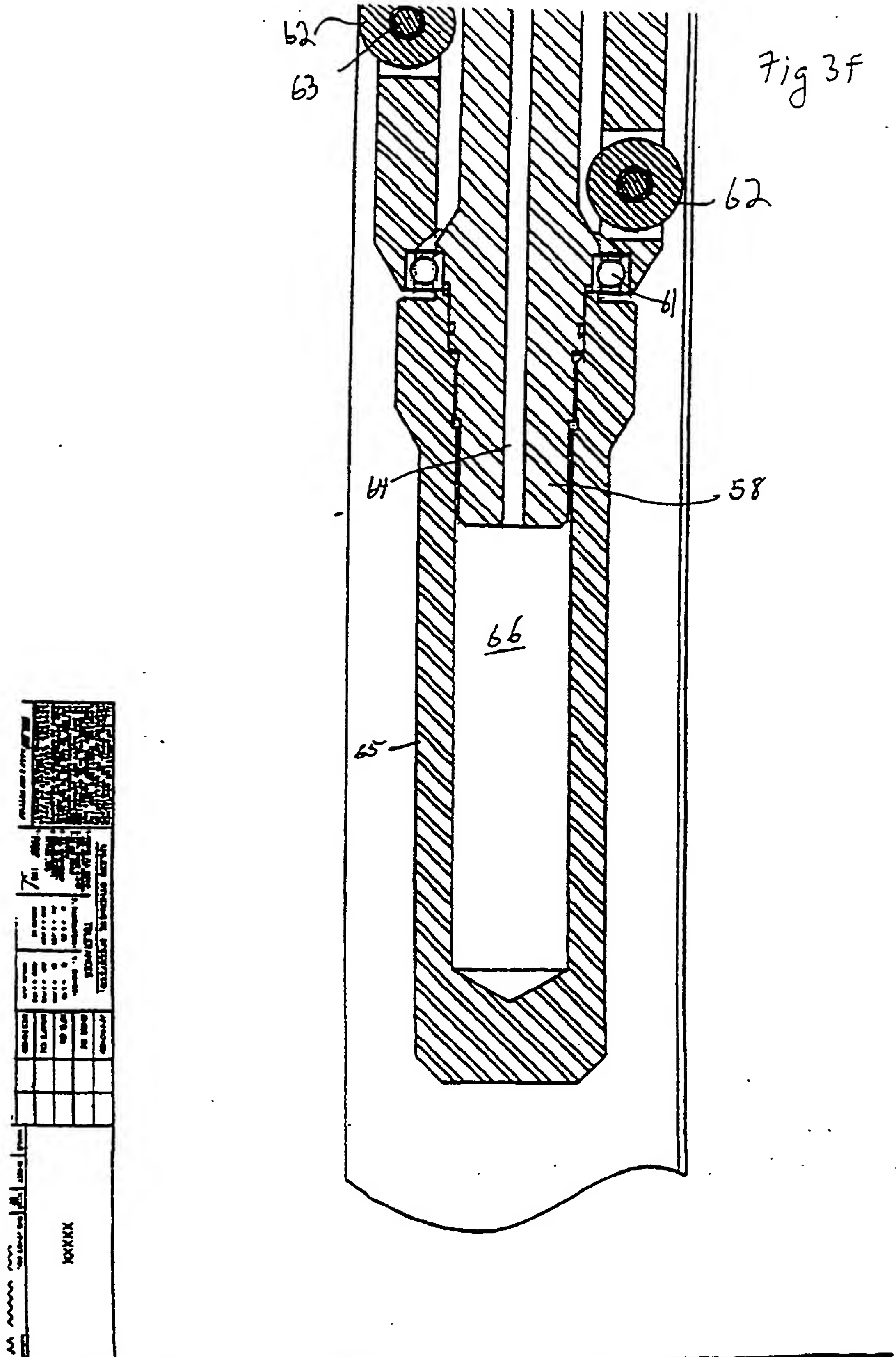


Fig 3E
46
50
52
51
53
55
56
58
59
60
CASING DRIFT DIAMETER



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